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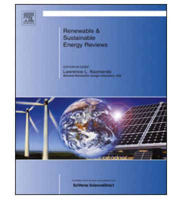

Recent progress in renewable energy – Remedy of energy crisis in Pakistan

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ABSTRACT

Energy plays a pivotal role for the economic development of a country. A reliable source of energy is needed to improve the living standard of people. Today, industrial progress plays a vital role in the development of any country but the industrial progress depends on reliable supply of electricity. However, Pakistan is passing through an energy crisis that is seriously affecting the lives of people. The main reason for the energy crisis is rapidly increasing the prices of hydro-carbon resources and lack of planning to foresee the increasing energy demand in the country. Renewable energy (RE) can play an important role to minimize this crisis. Besides the depletion of fossil fuel, the accumulation of their emissions has catastrophic effects on our environment. Modern civilizations are more curious about environmental cleanliness. Environmental pollution is supposed to be a serious threat to the life on our planet. Our earth could heat up by several degrees in future if we do not stop using non-renewable energy resources. In this article, the exiting production of renewable energy through different RE technologies is discussed and the potential capacity of production of energy through these technologies in Pakistan is studied. Some suggestions are also proposed to increase the RE share in the energy mix of the country.

Contents

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1. Introduction

The electrical power system has a major role in reshaping the modern society. Today industrial progress plays a vital role in the development of any country. But the industrial progress relies on reliable supply of electricity. Modern civilizations are more curious about environmental cleanliness. Environmental pollution is supposed to be a serious threat to life on the planet. Therefore use of green energy sources is spreading day by day throughout the world. The industrial and other sectors require reliable electricity supplies for their work. Therefore most of the countries are interested to penetrate the RE in their power sectors to obtain economic and environmental benefits. Depletion of fossil fuels in near future and accumulation of their emissions in the environment have attracted the world's attention to utilize renewable resources of energy. It is realized that a continuous reliance on fossil fuels will have catastrophic results because excessive carbon dioxide emission has dramatic global warming effects. Our earth could heat up by several degrees in future if we do not stop using non-renewable energy resources.

The global share of renewable energy in the power sector was 20.3% at the end of year 2011 [1]. The hydroelectric generation being the oldest and most mature form of bulk power generation has a share of 15.3% whereas only 5% was contributed by other renewable generations. Fig. 1 shows the global scenario of power generation.

Renewable energy generation has cost disadvantages when compared with non-renewable fossil fuel source of energy production [2]. Electricity production in Pakistan mainly depends on conventional sources of generation. During 2010–11, approximately 94,653 GWh of electricity was generated in the country. The main contributors in the energy mix are thermal power (62.5%), hydel (33.6%) and nuclear (3.9%) [32]. The share of renewable energy in the total energy mix is virtually negligible. The common perception about the renewable energy generation is the cost disadvantage but the increasing prices of fossil fuel in Pakistan and the abundant availability of renewable energy resources may help in achieving the grid parity.

However, in order to increase an environment friendly renewable energy production, many steps are needed to be taken by the governments of developing countries like Pakistan. A proper financial support system, such as tax rebates, feed in tariff and a mechanism to provide sufficient funds should be ensured by governments. Government can provide support to renewable energy generation in different manners. The large amount of CO_2, NO_x and CO_x emissions is caused by fossil fuel generation of electricity. A CO_2 emission tax helps the development of renewable energy sector and the other option is Feed-in-Tariff (FiT). FiT are the most commonly used renewable energy policy worldwide and considered one of the most attractive ways to boost the renewable energy generation by providing investor security [2]. Thailand was one of the first Asian countries to introduce the FiT program called Adder because it adds additional amount of payment to renewable energy producers on top of the normal energy prices that power companies would receive when selling electricity to the power utilities [3].

The motivation behind this research work is to look for recent trends of development in renewable energy technologies and their application as a solution for the power crisis in developing countries like Pakistan that mainly depends on fossil fuel for the electricity generation. The article is organized as follows: solar energy including solar photovoltaic and solar thermal renewable

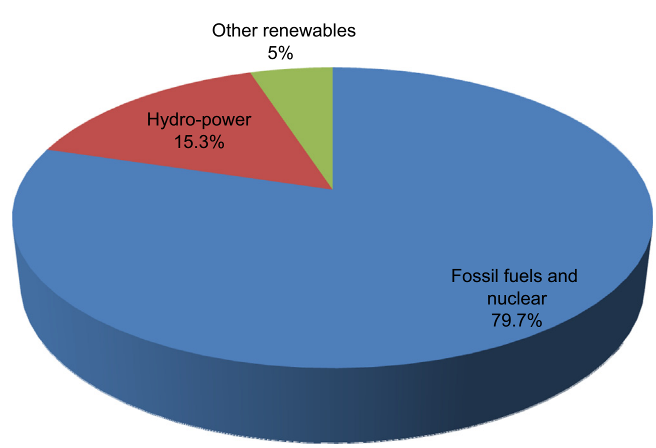

Fig. 1. Global scenario of power generation.

energy, their potential capacity and development in Pakistan is discussed in Section 2. Section 3 elaborates the recent progress for wind energy projects in Pakistan and worldwide while Section 4 discusses micro-hydel projects. Biomass renewable energy and its potential capacity in Pakistan are presented in Section 5. A discussion to critically analyze different sources is done in Section 6 and finally Section 7 concludes the article.

2. Solar energy

Solar technologies convert the solar radiations into electrical energy and it can be classified in two main groups, i.e. Photovoltaic technology and Thermal technology. Solar photovoltaic technology converts solar energy into direct current by the photovoltaic phenomenon. Solar thermal technologies use solar as a heating source and sunlight is concentrated onto a receiver.

2.1. Photovoltaic system

Solar energy can be converted into electrical energy using photovoltaic (PV) cells that gather the energy and store it in various storage systems. There is a potential to generate electricity in various parts of the world using solar energy. However, economic as well as installation issues are needed to be tackled to obtain maximum benefit. The sharp reduction in the cost of silicon based solar cells has resulted in dramatic increase of photovoltaic systems in many countries. In this section, various directions of research will be explored for realizing a solar renewable energy project.

Solar cell production is showing an annual growth of 37% in the past decade and this growth is even steeper during the past five years with an average annual growth of 45% [4]. Photovoltaic systems are really helpful in areas where electricity supply is intermittent or simply not available. The economic effects of placing new photovoltaic industry near to markets in highly solar irradiant developing countries where energy crises maybe faced in future is discussed in [5]. One such place with high solar irradiations is West Africa. In [5], technical and socio-economic assessment for silicon based low cast solar cells factory located in West Africa is elaborated. Solar cells cost (USD/watt) in West African countries is compared to the cost of solar cells produced in factories located in China and exported to West Africa.

As the photovoltaic technology is maturing and cost of PV systems is decreasing, the demand of this renewable energy technology in developing countries is increasing exponentially. In order to promote this technology and achieve grid parity, government policies can play an important role.

2.1.1. Government policies and cost factors

As the cost of solar cells is decreasing (Table 1) and a grid parity is achieved or closer to achieve in many regions around the world yet grid parity is far away in many countries around the globe. In order to increase an environment friendly photovoltaic system based renewable energy production, many steps need to be taken by the governments of such countries where grid parity is the major problem. A proper financial support system, such as tax rebates, feed in tariff and a mechanism to provide sufficient funds should be ensured by governments. A three-tier model to analyze the solar energy policies is presented in [4] and a PV adoption in Arizona, USA was chosen as a case study. The interrelationship among policies to support the solar energy is explained using three-tier model of policies.

Top tier – mandatory rules and regulations.
Middle tier – financial subsidy/incentive program.
Bottom tier – financial sources and funds collections.

Economic evaluation needs to be done before realizing a solar renewable energy project. In [6], an economic study of PV electric power for Quetta (Pakistan) is evaluated and it is shown that for this region, PV based electricity is about 30.8% more expensive than the grid supplied electricity. However, it considerably reduces the carbon dioxide production which is one of its advantages.

The issue of parity with grid produced electricity is quite confusing. The cost of PV energy system has already reached parity with grid [7] or on the other hand the PV energy is far more costly than the grid produced electricity [8,9]. These contrasting arguments are quite confusing for the users to make a decision whether such an investment is sane. These contrasting arguments are not surprising because many analysis of the cost and payback of solar PV systems do not consider the important factors affecting the cost of such systems. In [10], the authors compare the cost and financial payback for solar PV systems installed by businesses at different locations in USA. Case studies at four different locations across USA (Honolulu, Newark, Phoenix and Minneapolis) were carried out in [10]. The results show a dramatic variation in the cost and payback for solar PV systems installed at different locations.

The following factors must be considered while analyzing the feasibility of solar PV system:

- Both present costs of electricity and the inflation rate for grid produced electricity.
- The amount of solar insolation available.
- Cost of PV panels and related components.
- Government policies for financial support, for example, tax rebates to attract businesses to invest in solar PV energy systems.

2.1.2. Solar insolation

The insolation represents the cumulative sum of irradiance during a given time. Insolation is a measure of energy and it is the power of the sun added up over a given time period [37].

$$\text{Solar insolation} = \text{solar radiation} \times \text{time/area} = \text{irradiance} \times \text{time}$$

where, irradiance is a measurement of solar power and is defined as the rate at which solar energy falls onto a surface and its unit is Watts per square meter. The irradiance falling on a surface may vary from time to time that is why it is important to remember that irradiance is a measure of power.

As discussed above, the amount of solar radiation is an important factor for the feasibility of solar PV systems. The proper utilization of PV systems for the generation of electricity requires thorough and accurate information of global solar radiations.

Table 1
Cost of solar energy generated from PV cells [139].

Year	1977	1979	1981	1983	1985	1987	1989	1991	1993
Cost ($/Watt)	77	40	24	17	12.5	10	6	7	6.5
Year	1995	1997	1999	2001	2003	2007	2009	2011	2013
Cost ($/Watt)	5.8	5.5	5.5	4.5	4.3	3.5	1.8	1.3	0.74

Despite being the fundamental component of solar energy systems, the solar radiation data is only recorded on few meteorological stations [11,12]. Clouds and sunshine data are not easily available in majority of the meteorological stations. Therefore, for the estimation of solar radiations, daily solar radiations models using geographical location and air temperature are more attractive options because air temperature is recorded on most of the meteorological stations. In [13], the authors calibrate, validate and compare five models to estimate the global solar radiations. The objective is to develop models based on easily available data without sunshine or clouds data as input. Another study is conducted in [14] for the measurement of solar radiance in Central Spain during the span from 2002 to 2011. This shows the total accumulated Ultraviolet B (UV-B) radiations throughout the course of the year. This gives the data of solar radiation in a particular weather. This can help in optimal installation of solar panel in that specific region. Also, a study that was conducted in north-eastern Mexico that describes a climate model based on the recorded temperatures in that region [15].

Unfortunately, most of the meteorological stations measuring solar irradiations are located in developed countries. The solar irradiation data available on meteorological stations is normally based on horizontal measurements. In [16], a model is proposed to forecast the solar irradiation information on inclined surfaces based on horizontal irradiation measurements. The proposed model can help building designers to predict solar irradiation on inclined surface form the available data based on horizontal measurements. In [17], the impact of using solar radiance data for making energy calculations is discussed. Weather files were generated from the known data which can lead to the design of efficient buildings. Building designers generally use clear-sky solar radiation models. These models can be used in many solar radiation calculation procedures based on satellite data. One common problem while using a radiation model is related to the required input data versus the data actually available for a particular location and period. It is quite common that the potential user of a particular model with good accuracy do not have all the required input parameters. In this sort of situation, the user can either obtain the missing data by estimation which could introduce large error in the predicted radiance or use another model with less accuracy but works better with the available data. Viorel Badescu in [18] investigates fifty four clear sky solar radiation models. In these models, some only calculate global irradiance while others also give its direct and defuse components. The models accuracy is presented for different sets of input data. No model is found perfect for all sets of input data. However, some of the models are found better for most of the testing steps and perform better than others. Model accuracy and performance depends on the site of measurement and the quality of input data.

2.1.3. Orientation of solar cells

Another issue in solar cells installation is the orientation of the cells for maximizing the generated power. In [19], the effect of orientation of solar cells on the production of electricity is discussed. This study concludes that the angle of orientation can have significant impact on the generated electricity. It is advised to change the tilt angle twice a year for better results. Thus for each scenario, a study is required before installation in order to predict the period and tilt angle for the installed solar panel.

2.1.4. Power management in PV systems

A distributed photovoltaic (PV) possess a number of threats. As this can further lead to power management problem in the existing system where distributed users feed the generated power to the national grid. Ref. [20] describes the case study of Illinois for calculating the requirements of PV capacity penetration into the generation system. The optimum value needs to be calculated in order to have economic benefits. This research targets the development and validation of large scale solar PV systems in Illinois. Thus, one area of research and development is to explore the efficient ways of integrating the electricity into the grid.

2.1.5. Growth of renewable energy technologies

Solar energy being abundant and diverse in nature, with less intermittency around the globe, has shown high growth trend as compared to other renewable resources. The growth rates of different renewable energy technologies between 2006 and 2011 are shown in the Fig. 2 [1]. It is evident from Fig. 2 that Solar PV has the largest growth rate of 74% followed by Concentrating Solar Thermal Power (CSP) (35%), solar water heating (27%), wind power (20%), biodiesel (16%), hydropower (3%), geothermal power(1%) and ethanol production (−0.5%). Growth rate of ethanol production is −0.5% indicating that the interest in ethanol production has decreased in the last few years.

The main methods of harnessing solar energy for power generation are solar thermal generation and solar PV generation. Solar PV capacity has increased more rapidly during the last few years. The global installed capacity has increased from 2.2 GW in 2002 to 70 GW till the end of year 2011 which is depicted in Fig. 3 [1].

Germany has the largest installation capacity of PV systems in the world. PV installation in Germany has reached up to 32.4 GW in 2012 which is far more than other countries in the world.

2.1.6. Energy gains and environmental impact of PV systems

Generally, it is considered that PV technology consumes very small amount of energy and emits very little amount of Green House Gas (GHG) during its operation but this is not completely true. In fact, PV technology consumes large amount of energy and emits a considerable amount of GHG during its life span. Energy consumption and emissions are caused by manufacturing of solar cells and PV modules, transportation, installation and PV system`s disposal or recycling. Scientists have generally adopted Life Cycle Assessment (LCA) of PV systems for the detailed evaluation of their energy gains and environmental impacts. The most important LCA indicators are Energy Payback Time (EPBT), GHG emission rate and Greenhouse gas Payback Time (GPBT). These indicators may be used to study the sustainability and environmental benefits of different PV systems.

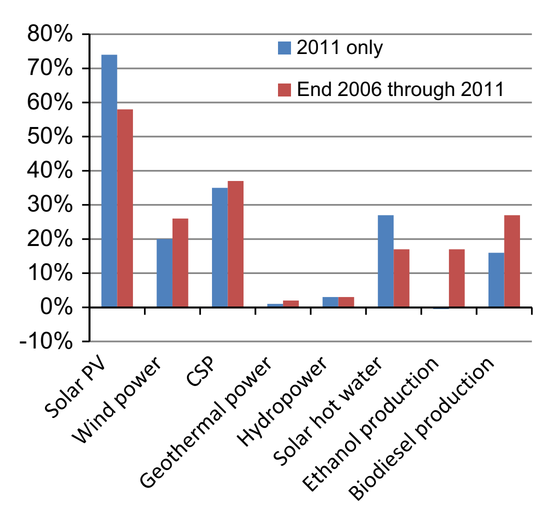

Fig. 2. Comparison of growth rates of renewable power generation.

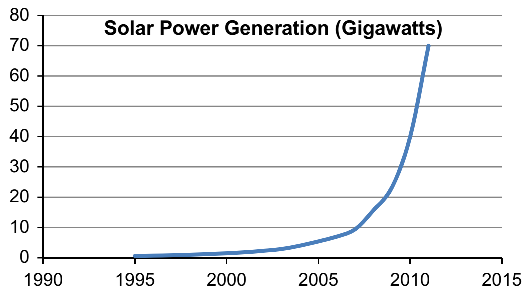

Fig. 3. Solar power generation.

2.1.6.1. Energy payback time (EPBT). Energy Payback Time (EPBT) is the time in years required by the PV system to produce the same amount of energy equal to the energy consumed during its life cycle [21].

$$\text{EPBT} = (E_{input} + E_{BOS})/E_{output}$$

where E_{input} is the energy consumed by PV module over the life cycle, E_{BOS} is the Balance of System (BOS) components energy requirement and E_{output} is the energy produced by the PV system.

2.1.6.2. Greenhouse payback time (GPBT). GPBT is defined as the sum of emissions of PV panels and their BOS divided by the emissions caused by the conventional power plant, generating the same amount of annual power as that of PV system.

$$\text{GPBT} = (\text{GHG}_{PV\ module} + \text{GHG}_{BOS})/\text{GHG}_{conv}$$

where $\text{GHG}_{PVmodule}$, GHG_{BOS} and GHG_{conv} are GHG emission of the PV module, GHG emissions of their BOS components and GHG emissions of conventional power plant (generating the power equivalent to that of PV system) respectively.

2.1.6.3. Energy yield ratio (EYR). EYR is the number of times the PV system can payback the energy input (total energy consumed over its life cycle) [22].

$$\text{EYR} = (E_{gen} \times L_{PV})/(E_{input} + E_{BOS})$$

where, E_{gen} is the annual electricity generation by PV system, L_{PV} is the life span of PV system (in years), E_{input} is the energy consumed by PV module over the life cycle, E_{BOS} is the balance of system (BOS) components energy requirement. An EYR greater than unity indicates the sustainability of PV system in terms of energy payback. Solar PV is not the only technology which converts sunlight into electricity. The other option could be solar thermal technologies.

2.2. Solar thermal

Solar thermal systems use concentrating mirrors to focus the sunlight onto a receiver which uses this energy to heat up the working fluid. This heated fluid is then used to run a turbine to generate electricity. Solar power plants work in two steps, first one is to collect the solar energy and convert it into heat and the second step is to convert the thermal energy into electricity. The use and production of solar energy has grown at a remarkable rate in recent years. The earth receives more solar energy in just one hour from sun than what the whole world consumes in one year [23]. Solar thermal energy is most widely available in both direct and indirect forms and is the most abundant of all the renewable energy sources. The sun energy reaches the surface of the earth at a rate of 1.08×10^{14} KW. A conversion of 0.1% of this energy at an efficiency of 10% would result in a four times generating capacity of the whole world which is 3000 GW. The total solar annual radiation reaching the surface of earth is 7500 times more than the total annual consumption of the world. The total annual radiations falling on earth are estimated around 3,400,000 EJ, which is greater than all the world's estimated, discovered or undiscovered nonconventional resources (including fossil fuels and nuclear).

2.2.1. Solar thermal power systems

This section concentrates on the generation of electrical and mechanical energy from solar thermal energy by processes mainly based on concentrating solar collectors and heat engines. These processes are parabolic trough solar collectors, tower collectors, parabolic dish collectors, linear Fresnel reflectors and solar ponds.

2.2.1.1. Parabolic trough. Parabolic trough consists of a series of curved mirrors which are used for concentrating the sunlight on thermal efficient receiver tubes located in the focal line of the trough. Synthetic oil, which is heated up to 400 °C by the concentrated sunlight through the receiver tubes, is used as a heat transfer medium. The synthetic oil transfers the heat from the collector to the heat exchanger where water is heated, evaporated and then converted into superheated steam which is used to run a turbine that runs a generator for the production of electricity. The cooled and condensed water comes back to the heat exchanger. These solar collectors are aligned north to south in solar fields. The collectors concentrate the sunlight by 70–100 times and the resultant temperatures are in the range of 350–450 °C. The efficiency of this technology is estimated to be around 15% [24].

2.2.1.2. Solar tower system. In solar tower power plants, heliostats (large two axis tracking mirror collectors) are used to track the sunrays and concentrate the sun`s radiant energy onto the receiver mounted on the tower. The energy from the receiver is transferred to a fluid at a temperature of more than 1500 °C. The heat transfer fluid could be liquid metal, water/steam, air or molten nitrate salt. This energy is then passed to the power conversion system for generation of electricity. The average solar energy flux on the receiver has a value from 200 KW/m^2 to 1000 KW/m^2. These systems are generally quite large, 10 MW or more [25].

2.2.1.3. Parabolic dish system. Parabolic dish collectors track the sunlight and concentrate it onto a receiver placed at the focal point of the dish. The receivers convert the absorbed energy into thermal energy. This thermal energy can be used for the generation of electricity. This system tracks the sun in two axis and therefore is very efficient and can achieve the temperature of more than 1500 ºC. The heated fluid in the receiver is used to drive a heat engine (Stirling engine) which is attached to the receiver. The annual solar to electric efficiency of parabolic dish plants is from 25% to 30% [26].

2.2.1.4. Linear Fresnel reflector. Linear Fresnel reflector (LFR) consists of an array of linear mirror strips. These linear mirror strips are used to concentrate sunlight onto a receiver which is mounted on a linear tower. An LFR field can be imagined as a broken up parabolic trough reflector but it is not parabolic in shape. The reflected sun rays are absorbed by large fixed absorber. The annual solar efficiency of this system is between 8% and 10% [26]. Though, this system is less efficient as compared to parabolic trough reflectors but the major advantage of LFR systems is that it is cheaper as compared to parabolic trough glass reflector thanks to the use of flat or elastically curved reflectors and fixed receiver [25].

2.2.1.5. Solar ponds. Solar ponds are constructed to collect and store the solar energy. These are basically artificially built ponds in

which high temperature is maintained in the lower region of the pond by preventing convection. Convection is usually prevented by the use of salt water and the ponds are generally called salt gradient solar ponds. In the last decade or so, many salt gradient solar ponds covering a surface area of few hundred to few thousand square meters have been constructed in many countries around the globe. The energy from these ponds can be extracted for different thermal applications for example greenhouse heating, agricultural applications, process heat in dairy form plants, desalination and power production. Different types and designs of solar ponds, their performance, factors affecting their performance, heat extraction modes, economic analysis and applications are reviewed in [27].

2.2.2. Solar thermal integration with conventional and non-conventional power plants

Hybridization, using both fossil fuels and solar energy, can be a lucrative option. Hybridization issues of solar thermal in generation plants are reviewed and analyzed in [28]. It is concluded that a properly designed hybrid plant can have clear upper hand and significant advantages over solar alone plants. These advantages include lower capital investments in relatively new technologies, better energy conversion efficiency and reduced energy cost.

2.2.3. The world solar resource

The sunniest areas around the globe (Sun Belt) with high solar radiations include Middle East, North Africa, Mediterranean, New Mexico, Arizona, California, Nevada etc. These sunny areas have high solar radiations and Concentrated Solar Power (CSP) can be considered a competitive source of power by 2020 [29].

The first CSP plant was built and remained operating in California during 1984–1991 but later on, a drop in prices of fossil fuel has led to a change of policy framework that was supporting the development of CSP [30]. The changes in policies in favor of solar power and government support for renewable energy generation such as feed in tariffs led the re-emergence of the CSP market in Spain and United states in 2006 [30]. Four solar thermal power plants with an overall capacity of 1000 MW have been approved by California Energy Commission in 2010. It has been estimated that the installed capacity of USA could be increased up to 118 GW by 2030 and about 1504 GW by 2050 [31]. Some 1500 MW of solar thermal plants are either in operation or under construction in Europe. The installed capacity of solar thermal power in Europe is expected to reach 30,000 MW by 2020. The installed capacity of this technology is expected to reach 83 GW by 2030 and 342 GW by 2050. In Spain, 81 MW of CSP is in operation and 839 MW are under construction [30].

2.2.3.1. CSP technology limitations in Europe. A successful CSP project requires sunlight in abundance and less populated areas. More than 40 CSP plants are already working in Europe but still this technology is facing many challenges in this area.

The most important challenges are

1) Most of the countries in Europe are not very sunny countries.
2) Obtaining land and terrain is very difficult in Europe.

Sunlight and irradiations play a very important role in CSP projects. There is no reason of having CSP plant without sufficient sunlight and irradiations. Fig. 4 shows that only Portugal, Spain, Greece and some part of Italy and France, with more than 2500

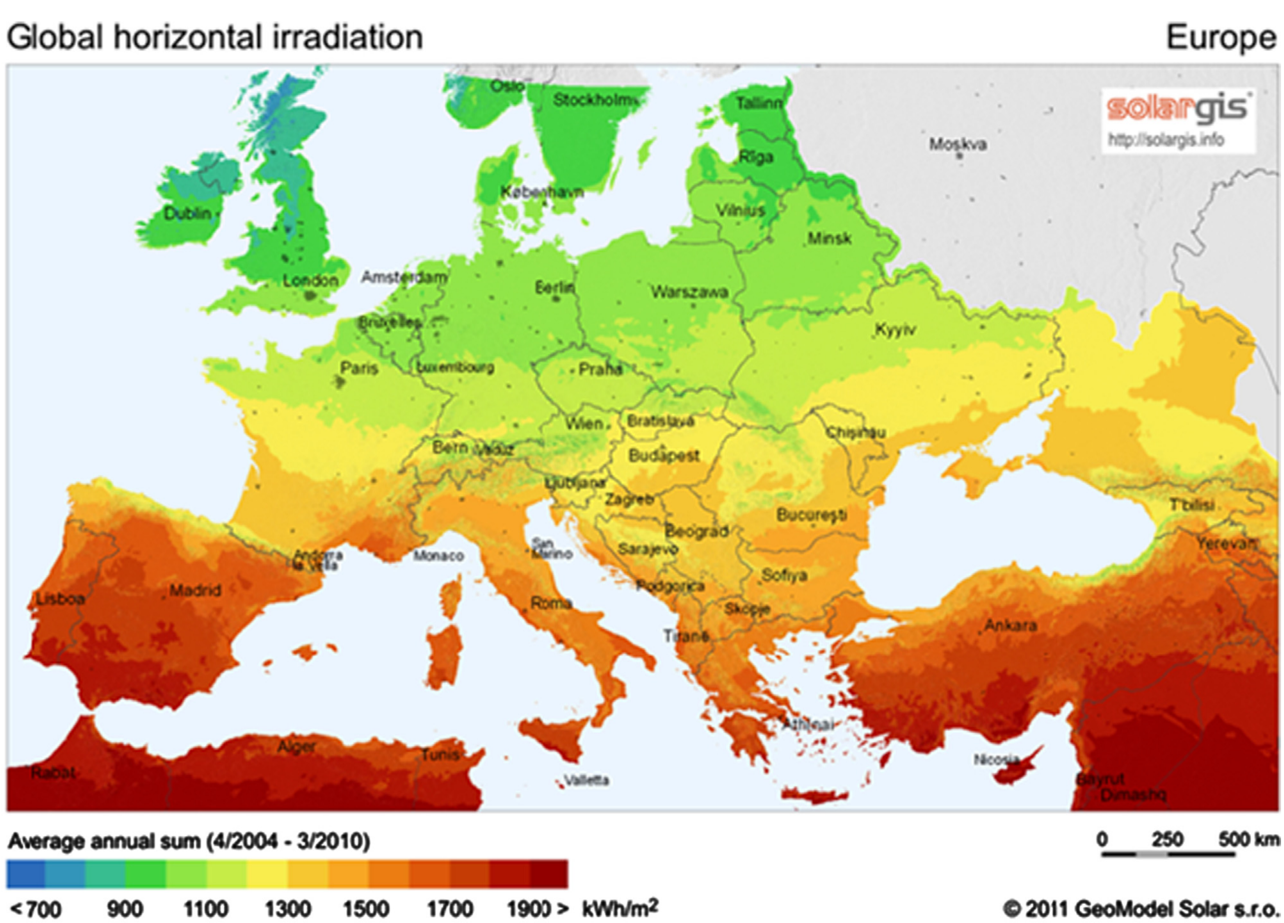

Fig. 4. Global solar irradiations in Europe [37].

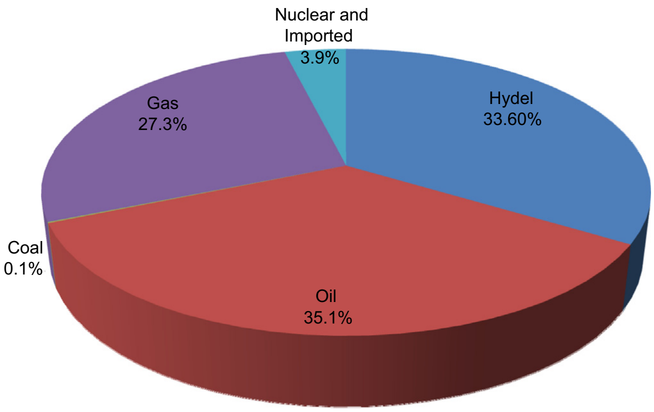

Fig. 5. The electricity generation share by source in Pakistan.

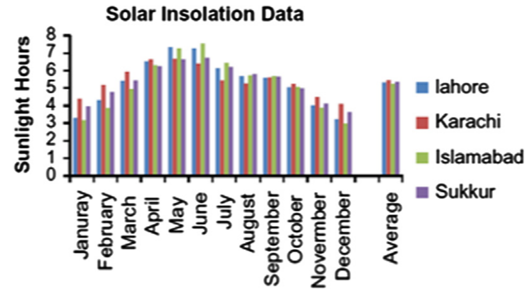

Fig. 6. Average solar insolation for major cities in Pakistan [37].

sunlight hours and irradiations between 1700 and 1900 KWh/m^2, could be considered for CSP projects. The second problem with CSP is the requirement of huge flat land. Europe is the second small continent (area wise) and the third most populous continent and because of the mountain nature of this continent, flat land for CSP collector is a big challenge.

One of the promising solutions to overcome the above mentioned challenges is to initiate CSP projects in Middle East and North Africa and transmit the electricity to Europe. These regions are some of the richest solar radiation places in the world [30].

Electrical power system has a major role in reshaping the modern society. Today industrial progress plays a vital role in the development of any country. But the industrial progress relies on reliable supply of electricity. Pakistan is facing a serious energy crisis and solar renewable energy could be an option because most area of the country is rich in solar irradiation.

2.3. Electricity crisis in Pakistan

The power sector of Pakistan relies on conventional sources of generation. According to Hydro-carbon Development Institute of Pakistan (HDIP) [32], 94,653 GWh of electricity was generated during 2010–11. The share of thermal power was 62.5% followed by hydel (33.6%) and nuclear (3.9%). In thermal power, oil had the largest share (35.1%) followed by natural gas (27.3%) and coal (0.1%) (Fig. 5). Solar and wind power is planned to be integrated in the power system; but except hydel no other renewable source is connected to the power system.

The power sector of Pakistan mainly depends on thermal power. Due to rapid increase in population, the use of fossil fuels has increased alarmingly. The problem of energy security, increasing prices of energy, the aspect of environmental pollution and depletion of the known fuel reserves in future have created a scope for utilization of renewable resources. Fossil fuels are mainly imported and the international trade routes are prone to conflicts and possess the potential of a severe energy security problem. Pakistan spends around 60% of its total foreign exchange on the import of fossil fuels [33]. The prices of these fossil fuels are subject to change which is not desirable and it aggravates the economic problems of the country. Increasing prices of fossil fuels and costs associated with emissions have severely affected the economy of the country. High oil prices have forced Pakistan to curtail the quantity of oil being imported in the country and as a result demand supply gap of electricity has increased and electricity crises has emerged. The total electricity capacity of the country has shifted from a surplus of 1230 MW in 2005 to a shortage of 5885 MW at the end of 2010 [34]. Although fossil fuels produce useful energy, they are responsible for production of harmful emissions like CO_2, SO_x, NO_x etc. The obvious choice available is to use renewable energy. The estimated potential of solar power in Pakistan is around 2900 GW [35].According to [36] the annual solar irradiance in the country is around 1900–2200 KWh/m^2.

High transmission and distribution losses, the problems of frequent disruption of grid supply power, financial constraints and difficulties to extend the grid to inaccessible remote areas are the main hurdles for the rural electrification in Pakistan. Off grid electrification can be a good option for the electricity facility for those remote areas where grid connection is unviable, both practically and economically. The solar energy option can be an excellent off grid alternative especially in those areas where there is no electricity and fossil fuel access is very difficult.

2.4. Solar energy options in Pakistan

Pakistan is a blessed country where sunlight is available in abundance. The solar insolation level in majority of cities is among the highest in the world. Pakistan can produce a significant amount of power from this most easily and readily available source of energy. Average solar insolation data of the major cities of Pakistan is shown in Fig. 6.

2.4.1. Global solar insolation for Pakistan

The estimated potential of solar power in Pakistan is around 2900 GW [35]. According to [36], the annual solar irradiance in the country is around 1900–2200 KWh/m^2. Global solar radiations are recorded at only five stations in Pakistan which are located in Karachi, Lahore, Multan, Peshawar and Quetta. Therefore, one has to rely on various empirical relationships for the estimation of solar radiations in other regions of Pakistan [38]. The annual mean daily solar radiations were developed in [38].

National Renewable Energy Laboratory (NREL) [37] developed the high resolution (10 km) seasonal and annual solar and wind resource map of Pakistan which is shown in Fig. 7.

2.4.2. Photovoltaic technology

The efficient way to convert solar energy directly into electricity is through PV systems. This technology is most suitable for small power needs applications in remote areas. Electricity generation cost from PV technology can be cut down by various initiatives from the government like indigenization of PV technology and duty free import of this technology. Local production of PV cells can result in a substantial reduction of cost of PV technology which will decrease the cost of generated electricity. The main constraints in the diffusion of PV technology are unawareness of local communities, unavailability of technical information and poor renewable energy policies [39].

Baluchistan is the largest province (area wise) of Pakistan with a population density of 21 persons/Km^2 and 77% of the population is living in remote rural areas. About 90% of these villages have no electricity facility. These villages are located at large distances

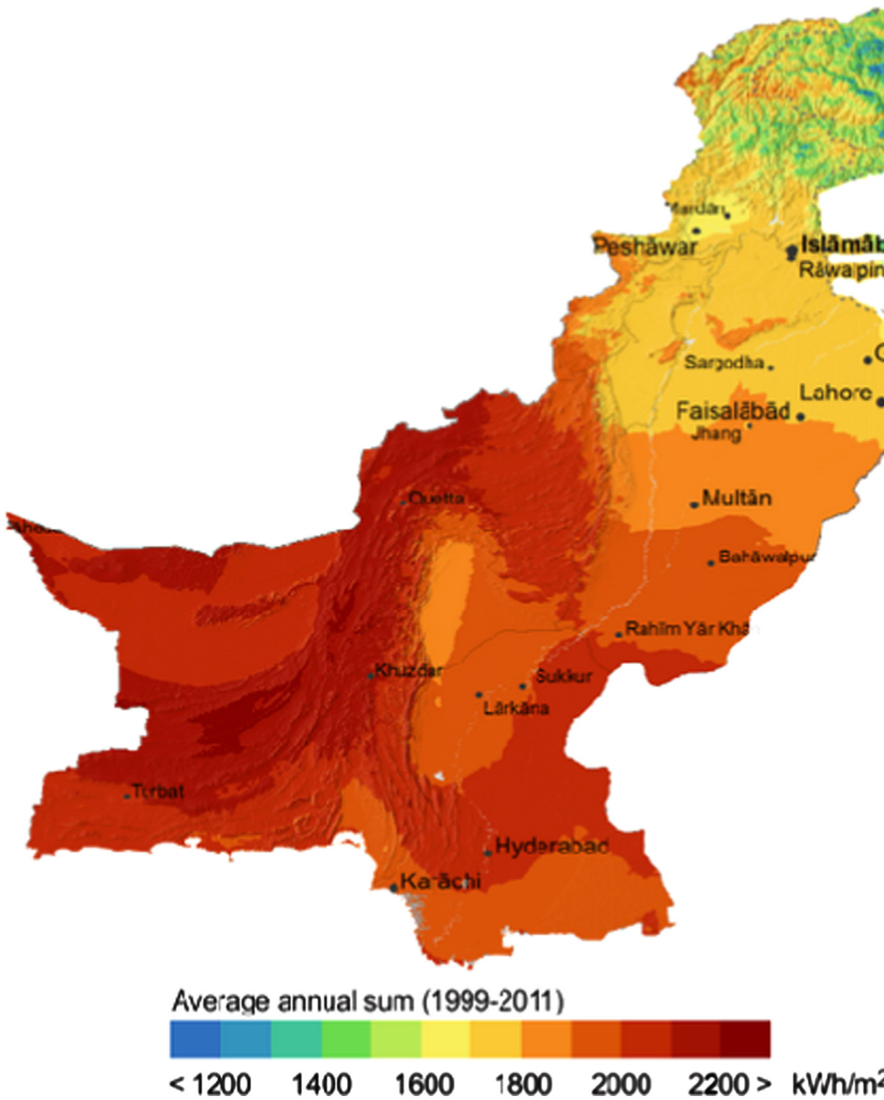

Fig. 7. Pakistan direct normal solar radiation map [37].

from each other; very far from the main lines as a result the transmission line construction for these areas is a very expensive option. Local power generation is the only suitable solution for these areas. Transportation of fuel, for the diesel generation, is a very expensive proposition. PV technology seems to be the only convenient option to provide electricity in these remote areas where grid connectivity is not feasible. This technology can be used conveniently in other remote areas like Cholistan (in the province of Punjab) and Thar deserts (Province of Sind) where solar radiation are quite high [41]. The grid connected areas are also facing energy interruption and are in dire need of alternative energy supplies because of some serious energy crises in the country. Urban areas of Pakistan are facing a load shedding of 8–10 h and 12–14 h in rural areas. This load shedding causing a severe dent to the country`s economy and Pakistan is losing 2.5 to 3 billion dollars per year due to the severe load shedding. A survey of World Bank [33] has reported that 66.7% businesses in Pakistan have identified load shedding as the main business obstacle.

Efforts have been made for the local fabrication of PV cells and small scale installation of PV systems in Pakistan. The local fabrication ability exists only at Pakistan Council of Renewable Energy Technology (PCRET) but its capabilities are still limited to pilot scale [42].Siemens Pakistan is actively involved in PV business in Pakistan for more than 10 years [40]. They have installed complete solar systems for house electrification, water pumping, telecommunication, highway communication, navigation, oil and gas fields and street lighting.

2.4.3. Solar thermal technology

Solar thermal technologies are relatively simple, low cost and comparatively easy to adopt. The potential application of these technologies in Pakistan is presented in Table 2.

3. Wind energy

The wind power can be used to generate electricity by converting the kinetic energy from the wind using wind turbines. The installation capacity of wind energy is expected to grow five times over the next ten years [45].Wind energy has been identified as one of the most important source of energy. Wind energy has become China`s third largest source of electricity after thermal and hydro power [46].Even though, a rapid growth in wind energy installations is expected, yet there are many constraints surrounding its development. These constraints are its intermittent nature, its seasonal and diurnal characteristics, its geographical locations and the infrastructure to transmit the wind energy to load centers.

Table 2
Solar Thermal Technologies in Pakistan.

Solar desalination	Solar desalination utilizes the sun's energy for the desalination of brackish or seawater and convert it into fresh drinkable water. A major problem for the people of Thar and Cholistan is the insufficiency of fresh water. Seawater is abundant in the coastal areas of the province of Baluchistan but drinkable water is unavailable. Solar desalination could be a blessing for the people of Sindh, Southern region of Punjab and coastline region of Balochistan. Two plants with a capacity of cleaning 6000 gallons/day have been installed in Baluchistan at the location of Gawadar and a number of schemes are under consideration in Baluchistan and Thar desert areas of Sindh and Punjab [43].
Solar water heaters	This technology utilizes sun's energy to heat water and according to Muneer and Asif [44], this technology is one of the fastest growing renewable energy technology in the world and has a great potential in Pakistan with a payback period of under 3 years. Different public and private sector organizations have been actively working on the cheap solar water heater. This technology is becoming popular in the northern areas of Pakistan with very cold weather and a limited supply of natural gas. Textile industry is the backbone of Pakistan`s economy and more than 60% of total export earning is coming from this industry but it is also one of the most energy consuming industry. Textile industry requires hot water with a temperature up to 80 °C. These heaters are very effective in applications that require 40–80 °*C* hot water. Solar water heating can save as much as 65% of the total conventional energy used for dying, finishing and curing processes [44]. Solar water heating can be an economical choice and can replace the conventional energy source. The payback period of this technology is estimated to be 6 years for textile industry of Pakistan by Muneer et al. in [44]. Solar water heating has proven to be efficient technology for the conversion of solar energy into thermal energy. The efficiency of this technology is about 70% as compared to the direct solar electrical conversion systems with efficiency of around 17%. Solar water heating is an important technology for the use in domestic and industrial sector due to its simple maintenance and operation. Extensive research efforts have resulted in the development of solar water heaters having significantly improved thermal performance. Various techniques for the improvement of thermal performance of solar water heaters and their limitations in existing research is carried by S. Jaisankar in [137].
Solar dryer	Drying is an important step in the post handling process of an agricultural produce. Traditionally agricultural crops were dried in the sunlight. Drying through solar radiations can be classified into two categories: (1) Open air or direct sun drying. (2) Indirect or convective solar drying. Open air drying is the most widespread method used in Pakistan for drying agricultural produce which results in the deterioration of the quality of the product because the product is unprotected against rain, wind, dust, birds, domestic animals and insects. Effective drying of agriculture product can be achieved by solar energy using solar dryer and quality of agriculture products can be improved at much lesser cost. Tons of fruits are wasted every year in the northern regions of Sakardu and Gilgit and the reason behind that is lack of basic infrastructure. Solar dryers are now being used to dry such fruits which are later transported in the urban areas. This results in the positive impact on the economy of these remote areas. Solar dryer could be equally important and effectively used in the Sind and Punjab provinces to dry agriculture products for higher market value [44]. There are many advantages of using solar dryer in industry for example less pollution, improved product quality and independence of unreliable supply of electricity and fossil fuels.
Solar cooker	A number of public and private sector organizations are working on the development of efficient and low cost designs of solar cookers. More than 5000 solar cookers are presently being used in Pakistan but the number is still less when we compare it with neighboring countries like India (14,500) and China (60,000) [44]. Pakistan needs to increase the population of solar cookers in order to reduce the consumption of forest resources as fuel wood. Food prepared in solar cookers retains their taste, natural flavor and vitamin content.

All of these potential constraints pose significant barriers to the development of this technology.

Extensive research is going on in countries which have favorable conditions for wind energy. Wind energy plants require wide open areas and sea shores because wind speed in such areas is high enough for the economical production of wind energy. Saudi Arabia is an example of one of such countries with long shore and wide open areas. Most of the research works on wind energy applications in Saudi Arabia have recommended it as the most promising and the economical source of energy in Saudi Arabia [47–55].

The feasibility analysis of any wind energy project in a country around the globe requires many steps. The first one is the selection of site for the project and for that purpose; we require the accurate wind speed data for many sites which may be potential candidate for the selection procedure of the best site. The second step is to determine the load curves of the load center. The third step is to find the optimal wind turbine. Here, the question arises, which one is the most suitable turbine for a particular site?

The answer to this question is provided by Ali M. Etamaly in [56]. This paper provides an accurate procedure for the design and implementation of wind energy in Saudi Arabia. In this paper, the author has proposed a new computer program to choose the best site for wind energy from many sites and suitable wind turbines for minimum cost of KWh of energy generated. The data from five sites and hundred wind turbines were used to choose the optimal site for wind energy production and best wind turbine for each site. This program can be used to choose the best site and suitable wind turbine for the selected site with infinite number of sites and wind turbines in all over the globe. This is so because of its flexibility to alter economic calculations according to any country in the word.

In [57], a study is carried out to show that due to rapid growth in energy consumption, there is an increase in air pollutant emission. If we compare the emission of carbon dioxide using a renewable source than it can be economically beneficial. Conventional power plants require a large amount of water for realizing the thermodynamic cycle [58]. This requirement is very less for the wind turbines. Also, production of electricity from wind energy has very low amount of carbon dioxide emissions [58]. Ref. [59] shows that wind energy is gaining interest throughout the world and it demonstrates the assessment of the wind energy in Germany and United States as these two countries are at the fore front of the world to use that energy resource. The research demonstrates the need of having further research for finding the strategic assessment of wind development. In this section, various wind energy projects, their impacts and practical considerations are discussed that are necessary for realizing such a project. Finally, a case study is discussed for effectively utilizing this technology in Pakistan.

3.1. Wind farms classifications

Wind energy has become a cost effective solution due to the present rise in fossil fuel prices as well as the greenhouse effect [60]. There are a number of studies that have been carried out on wind energy [61–63]. There are different types of wind energy farms based on the installation location of the project.

(1) Offshore wind energy
This type of wind energy farm is installed in the ocean and it can be an efficient solution for the countries where there is a shore located near their geographical location [64]. Such as South Korea that has a great capacity of offshore wind farms and it will install a 2.5 GW offshore wind farm in its Southwest sea by 2019 [65]. It is estimated that the offshore wind energy in the European Union (EU) from 2005 to 2020 is expected to increase from 2 TWh to 140 TWh [66]. In order to install an

offshore wind turbine (OWT), there needs to be a support structure that is constructed after considering various points. These design considerations include on-water depth, size of turbine and soil conditions. However, the maintenance of offshore energy plants is costly due to logistical complexity and this cost contributes up to 25–30% to the total cost of energy generation [67–69].

(2) Onshore wind energy
This is the classical wind farm that is installed in the open areas based on the wind conditions of the region. The wind speed should be high enough to make the application of wind energy economical [56]. A feasibility study is required to make sure whether wind energy production is economical or not. For example, studies conducted in [47–55] show that Saudi Arabia is an economical source of wind energy.

A suitable site will increase the production of electricity. Thus, site selection is an important phase for installing an offshore or an onshore wind farm.

3.2. Site selection for wind turbine installation

A detailed analysis of wind data and an accurate assessment of wind energy potential are the most important factors for the development of wind energy at any site. In [70], Khaled M. Bateinah and Doraid Dalalah have presented a technical assessment of wind energy potential at seven different locations across Jordan. They used Rayleigh distribution to model the monthly average wind data and estimated the wind power at the seven locations. Their energy cost analysis has shown a very high economic feasibility with a unit cost less than $0.4/KWh. Various steps that need to be followed for wind turbine installation are given in Table 3:

3.3. Life cycle assessment (LCA)

In terms of electricity production, wind power generation is one of the most 'environmental friendly' from the carbon dioxide emissions perspective [95]. However, there is a need to carry out LCA that identifies the main sources of carbon dioxide emissions during the life cycle of a wind farm. In this sub-section, various process steps that can influence the LCA are discussed [96]:

(1) Manufacturing
One of the major environmental impacts is from the manufacturing of turbine and its components. For example, LCA of electricity production from Vestas V112 Turbine Wind Plant [97] shows that largest impact is from the manufacturing

Table 3
Steps for wind turbine installation.

Step for wind turbine installation	Explanation
Wind energy resources/Atlas	Wind atlases play a very important role to determine wind resource in a particular area and eventually a fruitful site for wind energy. Environment Canada developed a wind energy atlas for Canada in 2004 [71]. This atlas covers almost entire country at a resolution of 5 km. In order to facilitate the initial site survey for a wind power project, high resolution maps of wind resources for different regions have been developed [72–74].These wind resource maps have influenced the public policies regarding wind energy development [75–76]. Truewind Solutions LLC developed a wind resource atlas of Southeast Asia, covering four countries including Thailand, Cambodia, Vietnam and Laos, at 1 km resolution [77]. Although this atlas shows a general description of wind resource distribution in a region but its resolution is too coarse to be used in site evaluation of a specific wind energy project. In [78], a high resolution wind atlas was developed for two provinces (Nakhon Si Thammarat and Songkhla) in southern Thailand at a resolution of 200 m. This atlas was verified by the wind speed data available from stations located in the given region along the coastlines. The potential wind energy annual production was calculated for two scenarios. One at 80 m above ground with wind turbines having hub height of 80 m and the other one at 40 m above ground level with wind turbines having hub height of 30–40 m. The analysis showed that power capacity at 80 m height is 1374 MW and annual production of 3.6 TWh. In 40 m scenario, wind farm of 407 MW (1 TWh annual) capacity could be installed using small wind turbines of 50 KW.
Accessing wind potential in marine instrumentation scarce area	However, in areas that do not have a wind atlas and have scarce marine instrumentation, wave records are only available during short period of time and that is not suitable for long term assessment. Example includes Caribbean Sea because marine instrumentation is scarce in that region. Furthermore, the available information is specific to some sites and is not general in nature [79]. Here, there is a need to access wind potential only in the targeted area to maximize the production of electricity.
Computer software optimal wind farm design and installation	For installing a wind energy system, a site needs to be chosen based on the minimum price of kWh generated from wind energy system. In [56], a computer program has been developed to perform an optimal design of the wind energy system. First of all, wind speed data has to be collected from selected sites. Secondly, load curves need to be supplied and last step is to collect the data of available turbines. Thus, the problem is to choose an optimal turbine for a specific site. The developed program in [56] can be applied to any region in the world to determine the economic feasibility of wind turbine installation.
Impact assessment (IA) regulations	Although, wind energy is regarded as an important source of renewable energy as it reduces the dependence on fossil fuels [80]. However, its development is not completely environment friendly due to its social and ecological conflicts [81]. The wind farms has a significant impact on land and seascapes [80–82] and it can cause noise and light emissions that can influence the neighbors and tourism in a region. There are studies that find out the impact of wind energy farms on birds [83–84]. Another concern with wind turbine is the potential interference with telecommunication equipment [58], as wind generators produce electric and magnetic fields. Thus, there is a need to have a balanced development of energy that minimizes these conflicts. The possible solution is to choose a site that minimizes the negative impacts of wind energy farms. There has to be a regulatory mechanism such as impact assessment (IA) in consultation with relevant public and private agencies for minimizing the negative effects. Developed countries like Germany and United States have their IA mechanisms in place. The analysis for IA regulations should consider the following points [59]: 1. Wind farms should be installed in less sensitive locations. 2. Strategic level assessments for a wind farm project should take place. This assessment focuses on the consideration of cumulative effects that might occur due to the decentralized deployment of wind farms. 3. Public involvement should be there as it provides several functions. As it lead to a better informed citizenry that facilitates the acceptance of the final decision [85–92]. 4. There is a need to have a certain degree of planning regarding the process of obtaining the required permissions [93,94].

stage. However, the energy required to manufacture and to transport the wind turbines for constructing a wind power plant equals the energy produced by the plant in a few months of operation [58].

(2) Construction and operation
The construction and operation phases account for small contributions to the carbon dioxide emissions. The LCA carried out for the Vestas V112 Turbine Wind Plant shows that it did not have significant contributions to overall impact [97–99].

(3) Transportation
The transportation also contributes to a relatively low percentage of total energy requirements for the wind farm installation. This has been verified by the studies conducted by VESTAS [97–100].

(4) End-of-life
A high percentage of wind energy generators are recycled and thus excluding this stage does not have a significant impact on the final results of LCA.

3.4. Wind farm installed capacity

As discussed earlier, wind energy is a clean form of renewable energy that has attracted much of the world's attention. The world production of wind energy has increased from 59, 322 MW to 254,000 MW from 2005 to 2012, respectively [101,102]. Thus, it is going to be a major portion of world's renewable electricity resource in the coming years. The Figs. 8 and 9 show the plot of top 10 nations that are generating electricity from this form of renewable energy. Germany was the leading nation in 2005 but in 2012 China is generating major portion of wind energy.

3.5. Case studies for economic and technical planning of wind renewable energy projects

For realizing a wind renewable energy project, there is a need to conduct economic and technical planning. There are a number of recent works that emphasize the need of this planning. [103] describes the case study of Sardinia (Italy) where the prices of electricity is double as compared to the rest of Italy. This research targets the potential of wind energy in that region. Based on the gathered information, the site of Bosa Marina has been proposed as a potential candidate for wind energy installation. Another study [104] targets the assessment of wind energy potential in United Kingdom (UK) while the assessment of wind energy prospects in Masdar city is described in [105]. The wind profile is obtained by experimentations and it is inferred that Masdar is a poor wind city as it can generate energy of 3307.88 MWh and 28.73 MWh at a height of 50m for large and small turbine, respectively. [96] describes the case study of wind power station consisting of 141.5 MW wind turbines that are situated in the north-eastern coast of Brazil. This analysis shows that the environmental impact of wind farms is small in terms of carbon dioxide emissions and thus it is feasible to implement the wind farms in the mentioned regions of Brazil to generate green electricity. The prospects of wind generation in the Binalood region of Iran and the long term wind speeds are discussed in [106]. It gives the numerical values of Weibull shape and Weibull scale parameters for installing the wind energy farms in the region. [107] describes the study for evaluating the wind power projects in Lebanon. The measurements were taken for about 1.5 years and it indicates that using the current technology, wind power cannot contribute to more than 12% target of the renewable energy produced in the country. The assessment of wind energy potential around Taiwan sea area is described in [108]. The effects of monsoon and typhoon that contributed to wind energy were analyzed using the data gathered from the Central Weather Bureau of Taiwan. The data was analyzed to get the spatial and temporal properties of wind energy potential in the considered region of Taiwan. The major contribution to this energy is from the monsoon and the average annual energy around the Island is approximately 16.9 TWh per year. The use of numerical modeling for accessing the effect of turbine array in the Tory Channel, New Zealand is discussed in [109]. The modeling shows that due to the location constraints, the produced power is much less than what is predicted by the proposed analysis. [110] discusses the potential of balance regarding PV and wind energy potentials in Europe. It is concluded that there is a need of further research effort for deployment of new renewable energy projects and hence will contribute to the production of green electricity. Governments need to increase the R&D support to achieve this goal. Hence, there is need for proper planning to assess the economic and technical consideration in a region. In order to overcome its energy crisis, Pakistan can also benefit from the recent experiences of the rest of the world to install wind farms.

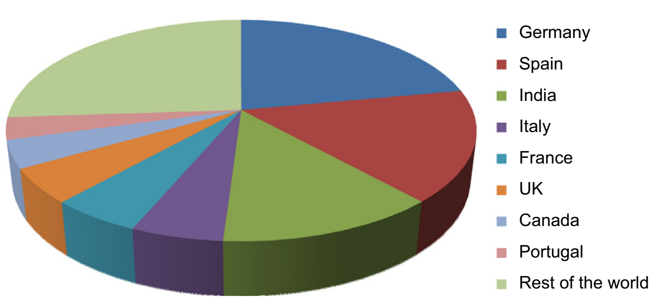

Fig. 8. Top 10 cumulative installed capacity (Dec 2005, World total=59,322 MW).

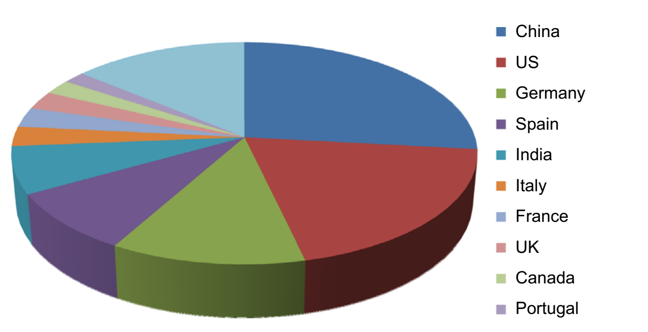

Fig. 9. Top 10 cumulative installed capacity (June 2012, World total=254,000 MW).

3.6. Wind energy in Pakistan [111]

In order to determine the feasibility for installment of wind turbines, there is a need to assess the distribution and characteristic of wind speed. The area of Pakistan in 803,950 km^2, and there is a potential of 360 GW as per the reports of Pakistan's Alternative Energy Development Board. This is illustrated in the wind map shown in Fig. 10 below developed by the National Renewable Energy Laboratory in collaboration with USAID. However, only 6.175 MW is being generated using the wind energy [112].

In 2009, it was announced by the Pakistan's Alternative Energy Development Agency that by 2022, 14% of total national energy will be produced from renewable resources. Maximum of which would be generated from the wind energy. The advantage of installing wind turbines in Pakistan is that it can be consumed independently in rural and remote areas that can increase the energy security of the country [113]. The initial effort to generate

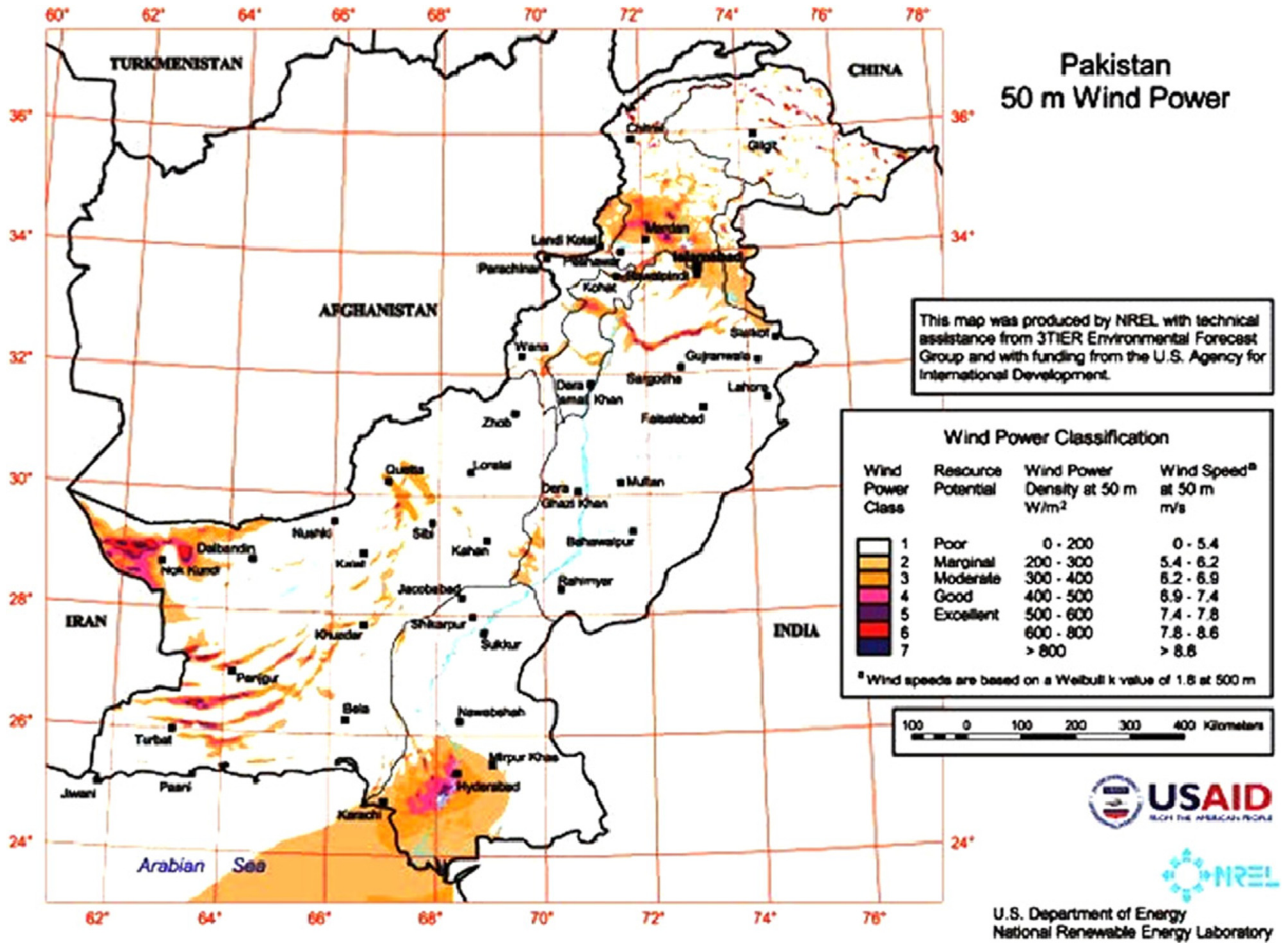

Fig. 10. Wind map developed by National Renewable Energy Laboratory (NREL), USA in collaboration with USAID [37].

electricity from wind energy was conducted in 1980s [114]. The wind turbines are not widespread due to unavailability of wind speed data at higher resolution. However, by looking at the 50 m resolution wind speed data given in Fig. 10, it can be seen that some areas of Balochistan, KPK and Sindh are most favorable for the wind turbine deployment.

As discussed previously, the global electricity produced from wind energy has been increased by nearly five times. There is a need to have further investment and research for the deployment of wind energy projects in Pakistan to fulfill the current power shortage. As discussed, the various steps that needs to be taken includes Wind Map generation, site selection, selection and manufacturing of wind turbines for a specific site, assessing the environmental and economic impact of wind turbine installation at a specific location and life cycle assessment of specific site, using computer software for selecting a particular type of available wind turbine.

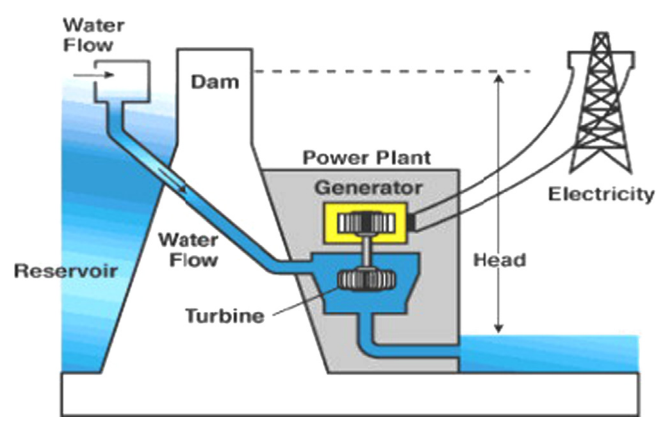

Fig. 11. Hydropower plant illustration [115].

4. Micro-hydro projects

Hydropower is renewable and clean form of electricity. These projects are designed after considering the requirements of a particular site. It also supports other water management services like flood control and drinking water supplies. The governing principles of a hydropower plant for electricity generation are simple. The potential energy of water that is elevated at a certain level is converted into kinetic energy. It is first converted into mechanical energy using a hydropower turbine and then to electric power using a generator [115]. The hydropower plant is illustrated in Fig. 11.

Micro-hydro projects are gaining interest in the domain of renewable energy as there are potential in various parts of world where it can be realized. Also, it is cheaper as compared to a mega hydro project that requires a lot of planning and displacing the population.

[116] describes the capacities of various small-scale hydro projects. The 'mini' hydro project typically refers to projects below 2 MW, micro-hydro below 500 kW and pico-hydro below 10 kW. In this section, various types of micro-hydro projects are discussed. There is also a discussion on installation procedures and

various projects that are going on around the world. Finally, the case study of Pakistan is discussed.

4.1. Types of micro-hydro projects

There are two types of micro-hydro projects. The first is to build a dam and make a water reservoir. The second one is called run-of-river scheme and it does not require a water reservoir; rather it takes water directly from the river to the power generation house where the turbines are installed. Table 4 explains these different types of micro-hydro projects.

4.2. Site selection

The selection and analysis of a site for micro-hydro project consists of following steps:

4.2.1. Data collection

There is a need to have a detailed survey for realizing a hydro power project. It includes selection of a proper site for the project after considering the economic and technical feasibility reports. The required data includes hydrological data, design flood, water quality and sediment transportation [117]. In situations where long term data is not available, an approximate method of determining utilization of rainfall data may be useful. Alongside rain fall data, air and water temperature, evaporation, annual climatic changes should also be known [117]. In order to determine the installed capacity, height of water fall, turbine type and discharge over long period of time need to be considered [118].

4.2.2. Data analysis and feasibility

After the completion of data collection phase, it needs to be analyzed. The first parameter that has to be considered includes the year wise rainfall data. Secondly, hydrographs are used to study hydrology of the surrounding area [117]. There is a need to assess the power and head calculations by considering the month wise releases, daily discharges etc. Based on this data a feasibility report is generated to see whether the proposed project is feasible by analyzing the economic and technical outcomes.

4.2.3. Expected energy generation calculations

Afterwards, there is a need to calculate the expected energy generated from a hydro power project. This varies from variations in rainfall pattern, maintained storage, irrigation requirement and cropping pattern [117]. Thus maximum and minimum energy generation potential can be determined for a year.

4.2.4. Environmental aspects

The environmental aspects should be considered for a proposed hydroelectric power project. The factors that need to be considered are submergence area due to plant construction, rehabilitation of people from submerged area, cutting of forests, etc [117]. Other effects include the effect on fisheries and other aquatic life. The proposed project should include the opportunities for the affected people during and after the realization of project.

4.3. Recent micro-hydro projects – Case studies

There are some recent projects that target this domain. [119] discusses a case study of South Africa that was conducted to evaluate the use of hydrokinetic energy. This study compares the results of generated energy with other sources of electricity. In [120], a comparison is performed for Turkey's hydro power generation with other developed nations. Discussion was done regarding the energy obtained from various resources and it was concluded that the hydroelectricity is under generated in most parts of the world. However, Turkey is producing a considerable amount of energy from hydroelectric. Thus, there is a need to exploit this direction to explore the ways to reduce the power crisis in various under developed parts of the world. [121] discusses the potential of small hydro projects in India where it can be a low cost electricity resource. Similarly, [122] discusses the potential of hydroelectricity in Malawi. At first, the article discusses the government reports and based on those reports an analysis is performed to find out the potential in hydroelectric power plants. Likewise, [123] analyses the potential of hydroelectricity in Greece that has a mountainous prefecture. Pakistan can also benefit from the experience of recently deployed micro-hydro projects to reduce its energy crisis.

4.4. Micro-hydro projects for Pakistan

As discussed earlier, Pakistan is currently passing through an energy crisis and it would be feasible to consider various renewable sources to generate electricity in order to minimize the power shortage. In such scenario, small scale renewable generation will be cost effective in terms of supplying the electricity to a remote community. One of such renewable resource that is available for mountainous regions of Pakistan can be utilized in terms of micro-hydro projects.

Pakistan Council of Renewable Energy Technologies (PCRET) [42] has attained a capacity of 3.5 MW using 290 micro and pico-hydro projects, with the participation of local community. These projects were of run-of-river type. The target of PCRET is to install micro-hydal plants of 20 MW capacities in northern Pakistan to provide electricity to 100,000 houses by 2020 [124]. Another organization namely Aga Khan Rural Support Program (AKRSP) has implemented 171 micro-hydro projects that provides electricity to 17,000 households in the isolated regions of Pakistan [125]. Example of a recent project includes community based micro-hydal plant at Chokana, Balakot and the project cost was 8750 USD with 10% community share.

Most of these projects are conducted in the Northern Areas of Pakistan because of absence of high power transmission lines. These projects normally provide electricity for night time and for some small industry operating in the region.

Table 4
Types of micro-hydro project.

Type of micro-hydro project	Explanation
Run-of-river projects	It is a simple and cheap micro-hydro project as it does not require any dam reservoir. However, it requires some sort of river diversion structure to carry the water into the power turbine for generating the electricity. Thus, the problem is the flow of water which changes over the period of time, thus the characteristics of generated power also fluctuates. This requires efficient power electronics devices to remove the fluctuations in the electricity [115].
Dam projects	The second type of micro-hydro project requires constructing a reservoir for storage of water in order to generate the electricity. This also provides some control over the flow of water and it can be used to avoid the floods and other disastrous situations.

As mentioned in this section, there is a need to exploit the renewable resources in order to minimize the shortage of electricity in Pakistan. Northern areas of Pakistan have a capacity to install a number of run-of-river projects to realize a micro-hydal plant. There is a need to have a proper survey in the mountainous regions of Pakistan to identify the potential sites for run-of-river projects; as these are cost effective renewable energy resource. This can help to locally minimize the short fall of electricity in the region and this decentralized mechanism will help to develop the remote areas of Pakistan as well.

5. Biomass renewable energy

Biomass is a sustainable renewable energy source and is widely available. Its production and use has additional social and environmental benefits. If correctly managed; biomass is a sustainable source of renewable energy that can result in a significant reduction in net carbon emissions when compared with fossil fuels. The energy conversion efficiency of the conventional fossil fuel technologies can be high but they are quite inefficient in carbon conversion because of high CO_2 emissions [126]. Biomass can be a good alternative to the use of fossil fuel because it presents many economic and environmental benefits.

The palm oil renewable energy industry information is presented in [127]. Palm oil industry is one of Malaysia`s premier agricultural enterprise and contributes 85.5% of the total biomass production in Malaysia. Therefore biomass from this industry can be a great source of renewable energy generation. Its conversion to renewable energy will reduce the waste from this industry and thus minimizes its environmental effects. The annual production of palm oil biomass residue in Malaysia is 53 million tonnes with an annual growth of 5%. It is expected to rise to 100 million tonnes of dry biomass till 2020 [127].

A detailed survey of the perceptions of Nepalese foresters about the bio energy development in Nepal is presented in [128]. The government of Nepal has recently announced a state of national energy crises in the country. Modern bio energy technologies have been realized as one of the major attractive energy source to overcome energy crises in the country. A bio energy support program (BSP) was established back in 1992. This BSP is a success story in Nepal and more than 25,000 plants have been installed by 2010 [128,129].

Depletion of fossil fuels in near future and their emissions have attracted the world`s attention to find alternative options. In order to mitigate the problems related to fossil fuels, bio fuels have been recognized as one of the options. Bio fuel projects are another paradigm of renewable energy research where non-fossil fuel is used to minimize the atmospheric carbon dioxide contents. Bio ethanol is one of the bio fuel that can be produced from different biomass materials. A detailed study to identify the available feedstock for bio ethanol in Ghana was carried out in [130]. Cassava, Yam and Maize were identified as the potential energy crops and Cassava was found to be the most suitable crop for bio ethanol production.

European Union (EU) has set a goal to increase the share of renewable energy sources up to 20% of the total energy consumed by 2020. It would be mandatory for each EU country to replace at least 10% of transport fuel with bio fuel [131]. Many countries in the developed world are already using a significant percentage of bio fuels to meet their energy demand. Bio energy is sustainable in many regions of the EU countries because bio energy crops and forest plantations are established in these regions [131,132]. Ref. [133] describes the use of bio energy in various communities and this article presents the concept of bio energy villages by cultivating more and more area of land to reduce the carbon dioxide emissions. It provides the example of a German village where the results show that 100% energy demand in a village can be fulfilled from the boundaries of the locality.

In [134], a case study of South Korea is presented for finding an optimized location of combined heat and power plants (CHP). Results show that using the abundant forest resources in South Korea, there is great potential to bio energy in place of fossil fuel. However, the transport fuel production from energy crops has a number of negative impacts. There are many issues related to the use of bio fuel that includes low efficiency and emission of hazardous gases which can be reduced by the government's energy policies. Thus, it can be an interesting direction of research. Biomass could lead to the intensive forests management which may have negative impacts on our economy and environment. In order to reduce the environmental hazards, biomass energy production must be limited to sustainable development of forests [135].

5.1. *Biomass/biogas technology – Applications and potentials in Pakistan*

The Biogas technology presents an excellent option to utilize biomass. Anaerobic fermentation of organic materials like agricultural wastes, animal dung, aquatic weeds etc. produces methane rich fuel gas and an organic fertilizer. In 2007, PCRET started a project to install 2500 biogas plants. Despite various financial constrains some 2000 biogas units have been successfully installed whereas work is going on for the installation of other 500 units [42]. Initially, biogas plants were constructed only for cooking purpose but the recent severe energy crises in the country has compelled the authorities to work up the possibilities to utilize the biogas on commercial scale. The galloping fuel has forced agriculturists to use biogas for running the tube wells. Relatively large size biogas plants have been installed in different regions of the province of Punjab which includes Narowal, Jhang, Sialkot and other places. The success rate of these plants is recorded very high [42].

There are about 51 million animals in Pakistan which could produce 19.125 million M3 biogas daily through anaerobic fermentation of animal dung using 3.825 million family size biogas units [42].

As per recent livestock census, there are 51 million animals (buffaloes, cows, bullocks) in Pakistan. Anaerobic fermentation of these animals dung can produce enough biogas to meet the cooking requirement of 50 million people. More than 100 million people out of total population of 170 million live in rural areas of Pakistan. Therefore we can meet the cooking/heating needs of about 44% rural population from this single source of energy. Besides biogas, this technology produces 57.4 million Kg nitrogen enriched bio fertilizer daily which is very essential thing for fertility of agriculture land [42].

6. Discussion

Renewable energy is an important form of electricity production as it can reduce the pollution in the environment. However, the electricity generated using the renewable sources needs to be critically analyzed in order to ensure green energy production. In this section, the renewable sources are discussed based on the literature survey presented in the article:

6.1. *Solar energy*

In this section, some open issues for future research in solar energy are presented.

1) PV manufacturing factories can be placed near highly solar irradiant countries. The production factories close to distribution

centers allow customizing PV panels with lower costs. One such option could be PV factories in Pakistan. Pakistan is a blessed country where sunlight is available in abundance. The solar insolation level in majority of cities is among the highest in the world. Pakistan is rich in solar radiations and labor cost is very low (Rs. 9000 or $85/month). Pakistan could be a potential candidate from financial benefits point of view as well. Baluchistan is the largest province (area wise) of Pakistan with 77% of the population living in remote rural areas. About 90% of these villages have no electricity facility. These villages are located very far from the main lines and transmission line construction for these areas is a very expensive option. Local power generation is the only suitable solution for these areas. Renewable technologies promise not only energy security at affordable cost but can speed up the development of these rural areas. Since these areas are located very far from the main cities therefore land prices for the manufacturing factories are very low and most of the local population does not have a proper work. In general, the most labor intensive stage in the production of PV modules is solar cell manufacturing, module framing and stringing. There is no need of specialized labor for work related to these processes. The training from the machine supplier is enough in most of the cases. Cheap local labor is available to carry out these processes.

2) The previous work lacks the research on interrelationship among renewable energy policies supporting the solar energy promotion. The government can set a renewable energy adoption target but the target can only be achieved through a proper financial support procedure such as tax rebates, incentives and add on tariff. This financial support mechanism requires financial sources to support the financial support mechanism. In order to boost the renewable energy production in the country, the government should make the policies in three steps which are strongly interlinked through loop. The first element in the loop is to design rules and regulations and set a target, the second step is to provide/calculate amount or subsidies to fund the financial support program and the last step is to find sources to fund the financial support program. If the financial resources are not sufficient to fund the program then come to the first step and reset the new target. This three tier loop/model is very important in long term policies. The government subsidies are good but if proper financial sources are not developed, especially in a country with political uncertainties like Pakistan, the subsidies life could be very short and as a result the target would not be achieved.
3) The problem of solar energy share in the overall energy mix in the countries where flat land is not easily available and solar radiation level is very low can be solved by installing CSP plants in Middle East and North African countries. The generated solar power can be transmitted via high voltage DC transmission lines to the countries with lower solar radiation level like European countries.

6.2. *Wind energy*

This is an important source of renewable energy with a global installed capacity of 238,351 MW [138]. Among the top 10 wind power countries in the world, China has the highest growth rate of around 98% over the period of 2005–2011. The next highest growth rate from the year 2005 to 2011 is for France (88%), Canada (87%), USA (80%) and UK (79%), that implies the significance of wind energy [138].

The wind energy generation farms are of two types: on-shore and off-shore. In order to install a wind farm at a new location, there is a need to have an extensive survey to access the wind potential. If wind energy chart is not available, then it has to be accessed for a chosen location. On-shore or off-shore farms can be deployed based on the land availability. The next step is the proper selection of a wind turbine.

The other aspect that has to be considered is minimization of environmental impact of the wind turbine that results in greener electricity production. This will help to minimize the environmental hazards. Also, the production of tidal energy is variable and this needs to be predicted. This requires extensive on-site measurements and a credible analysis of the site. The detailed data would enable in reliable assessment for system balancing. Finally, governments need to invest more into the wind energy in order to minimize the electricity shortage in developing countries like Pakistan.

6.3. *Micro-hydel energy*

The water is a very important resource for the existence of life and it is used in agriculture as an irrigation resource. Hydro power has many characteristics such as it is clean, less destructive to environment and inexpensive [120]. This form of energy production is the largest renewable resource globally. According to [120], China is the largest producer of hydro power (616 TWh/yr) followed by Brazil (391 TWh/yr), Canada (364 TWh/yr), the United States (298 TWh/yr), Russian Federation (176 TWh/yr), Norway (127 TWh/yr), and India (107 TWh/yr). Half of the total hydro production in the world is from the first four leading countries.

This is an important aspect of research and there is a potential to generate a cheaper form of renewable energy. The energy consumption requirements of a country can effectively describe its economic growth. This is due to many factors such as high birth rates, living styles and industrialization. Hydro power is a form of energy that can be produced in a cheaper manner and it can meet the growing requirements of a developing country. There are also a number of sites worldwide where run-off river projects can be installed to generate electricity. Likewise, governments have to invest in this direction in order to minimize electricity crisis in developing countries like Pakistan.

6.4. *Biomass energy*

Biogas has proved to be a viable technology in the physical and socio-economic conditions. There is a lot of Biogas potential in Pakistan. This technology can provide almost three times more useful energy than that dung directly burnt. This technology can improve economic condition of the rural area population of the country. The other advantage is abating the emissions of GHG that would pollute the environment due to its direct exposure. This technology is environment friendly because it reduces emissions and develops healthy environment. At present, Pakistan does not have a single biomass/waste power plant. There are nearly 51 million animals in Pakistan and anaerobic fermentation of the animal dung can produce enough biogas to meet cooking need of half of the rural population.

6.5. *Suggestions to promote RE in Pakistan*

Government of Pakistan should take the following steps to increase the share of RE in the energy mix of the national grid:

- Wind Risk (risk of variability of wind speed).
- Guaranteed electricity purchase.
- Grid provision is the responsibility of the purchaser.
- Protection against political risk.
- Attractive tariff, indexed to inflation and exchange rate variation.
- Carbon credits available.

- No import duties on equipment.
- Exemption on income tax/withholding tax and sales tax.

7. Conclusion

Energy plays an important role for the economic development of a country. In this article, the exiting production of renewable energy through different RE technologies is discussed and the potential capacity of production of energy through these technologies in Pakistan is studied. Pakistan Council of Renewable Energy Technology (PCRET) and Pakistan Council of Scientific and Industrial Research (PCSIR) have developed and indigenously fabricated many solar appliances which include solar space heating system, solar water heater, solar cooker, solar dryer and solar desalination stills. Private sector is playing an important role in promoting and upgrading of PV technology in the country.

Further steps are needed to be taken for the development of the locally built technology for the reduction of cost for renewable energy generation. Financial support, attractive incentives, research and development programs are required for the growth of renewable energy for electricity generation in the country. Cost of renewable energy production can be reduced by giving tax incentives and duty relief on the import of this renewable energy technology.

Pakistan Council for Renewable Energy Technology was started in 2001 and its goal was to ensure development of renewable energy projects in the country. Alternative Energy Development Board (AEDB) was establish in 2003 to join such efforts but unfortunately both of the government organizations were failed to achieve any major breakthrough due to poor technical manpower and weak financial recourses. Following targets were set in the National Renewable Energy Policy (NREP) 2002.

1) The share of renewable energy in national energy mix will be 3%.
2) 2% of the annual development budget will be given for the renewable energy technologies development.
3) All localities which are anticipated to be integrated in the national grid in coming 30 years are to be reserved for renewable energy resources.

In 2013, Pakistan is no way near to achieve these targets. Renewable energy is virtually negligible of the total energy mix in 2012.

It is expected that the suggestions included in this article by surveying the recent renewable energy projects can be helpful for concerned authorities to minimize energy crisis in Pakistan. Other developing countries having the similar dynamics can also benefit from this research.

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